Development of Accommodation Models for Soldiers in Vehicles: Squad

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CONTENTS

ABSTRACT

Data from a previous study of Soldier posture and position were analyzed to develop statistical models to define accommodation in squad seating positions in military ground vehicles. Using methods previously developed for automotive applications, new models were created for eye location, head (helmet) contour, and knee contour for Soldiers in fixed seats. The models are applicable to a range of seat height and seat back angle. All of the models include the effects of body armor and body borne gear.

INTRODUCTION

The design of military ground vehicles in the United States is guided in part by Military Standard (MIL-STD) 1472G, Human Engineering, a design standard that encompasses a broad array of normative data for human needs and performance. A small section of this standard addresses the design of vehicle seats and the layout of the driver workstation. However, this guidance is out of date and incomplete in many respects. For example, the standard is not based on distributions of Soldier body dimensions and postures from modern studies, does not specify appropriate clearances and space required for Soldiers wearing body armor and body borne gear, and does not adequately take into account the effects of body armor on Soldier posture and position in squad seating.

SAE International (formerly the Society of Automotive Engineers) has codified several design standards for passenger vehicle seats with fixed seats typical of rear seating environments (SAE International 2013). SAE Recommended Practice J941 includes a statistical model for eye locations in rear seats (Reed 2011), and the head clearance contour in Recommended Practice J1052 includes a contour for rear seats. However, these practices are not based on Soldier data and do not take into account the effects of body born gear and protective equipment, such as helmets. The SAE practices also do not present guidance on knee clearance.

This report presents the methods and outputs for accommodation models for Soldiers in squad seating conditions, defined as fixed (non-adjustable) seats, typically in the rear of vehicles. Data from the Seated Soldier Study (Reed and Ebert 2013) were used to develop an eyellipse, helmet contour, and knee contour. This report is a companion to UMTRI-2014-26, "Development of Accommodation Models for Soldiers in Vehicles: Driver" (Zerehsaz et al. 2014), which presents analogous models for drivers.

METHODS

Data Source and Applicable Ranges

The data used for the current analysis were gathered in the Seated Soldier Study (Reed and Ebert 2013). Posture and position data were recorded for male and female enlisted personnel at three Army posts as they sat in a squad mockup (Figure 1).

Figure 1. Squad mockup.

The current study used data from 144 men and women tested in the squad mockup. Table 1 lists summary statistics for standard anthropometric variables for the combined male/female population. (For single-gender populations and distribution data for more anthropometric measures, see the Seated Soldier report.)

Table 1
Anthropometric Characteristics of the Squad Population (combined men and women)

Variable	Mean	SD	5th%ile	50th%ile	95th%ile
Stature (mm)	1736	85.3	1591	1735	1852
Body Weight (kg)	80.2	14.5	58.9	79.9	103.3
Erect Sitting Height (mm)	909	45.6	826	913	975
Sitting Height / Stature	0.524	0.0147	0.500	0.524	0.545
BMI (kg/m^2)	26.5	3.73	21.4	26.5	33.4

Figure 2 shows the ensemble levels used for measurements in the mockup. At the Advanced Combat Uniform (ACU) level, Soldiers wore their own advanced combat uniform consisting of a jacket, trousers, moisture-wicking shirt and brown combat boots. All items were removed from the pockets, extra padding removed from the knees, and any cap or helmet removed. At the Personal Protective Equipment (PPE) level, Soldiers wore an Improved Outer Tactical Vest (IOTV) with Enhanced Small Arms Protective Insert (ESAPI) plates, Enhanced Side Ballistic Inserts (ESBI), and an Advanced Combat Helmet (ACH) over their ACU ensemble. Five sizes of IOTV were available at the study site. The Soldiers were given their self-reported sizes of helmet and IOTV with front, back and side plates. The investigator helped the Soldier don the PPE and checked the fit. The fit was considered acceptable if (1) the elastic waistband of the IOTV was snug with the Velcro closure fully overlapped and (2) the bottom of the IOTV was located below the navel and above the belt. The Soldiers wore the smallest size helmet in which the Soldier's head was in contact with the padding on the inside of the top of the helmet.

The third level of gear was referred to as encumbered (ENC), which consisted of ACU, PPE, a hydration pack, and a Tactical Assault Panel (TAP) with a SAW gunner kit. Figure 2 shows the ensemble levels. Note that a Rifleman kit was included in the Seated Soldier Study but only worn by Soldiers tested in the driver mockup. All squad data at the ENC level are for Soldiers wearing the SAW kit.

ACU PPE ENC (SAW Gunner)

Figure 2. Three ensembles worn during measurement: ACU, PPE and ENC (left to right).

Table 2 shows the squad mockup conditions. The test seat was set to two combinations of back angle and cushion angle. Seat height was effectively lowered by elevating the foot rest surface, including adding a 60-mm block to simulate a "foot protection" condition in which an elevated footrest is provided. Foot positions were restricted as shown in the table. PPE and ENC were tested only in conditions 1 and 1A. Soldier posture data were gathered using a FARO Arm coordinate digitizer (Reed and Ebert 2013).

Table 2
Condition Matrix for Squad Mockup

Block†	Conditions†	Back Angle	Cushion Angle	H30: Seat Height (mm)	Foot ** Protection H30 -60 mm	Foot Position Forward of Seat H-point	
						Toe	Heel
1	**1***	0°	0°	450 (floor)	No	575	
	1A*	0°	0°	450 (floor)	Yes (Block)		425
	2	0°	0°	350 (platform)	No	575	
	2A	0°	0°	350 (platform)	Yes (Block)		425
3	*5*	10°	5°	450 (floor)	No	575	
	6	10°	5°	450 (floor)	Yes (Block)		425
	7	10°	5°	350 (platform)	No	575	
	8	10°	5°	350 (platform)	Yes (Block)		425

†Block 2 and associated conditions (3, 4) were deleted after pilot measurements due to time constraints.
*Repeated with PPE and ENC
**Foot protection 380 x 280 x 60 mm

In general, the models presented in this report are valid over the range of conditions present in the underlying data. However, a small amount of extrapolation is reasonable given the linear trends observed in this work and experience in previous studies with civilian passenger postures. Table 3 lists the relevant ranges of individual parameters including maximum recommended extrapolation. In general, errors will be larger with greater extrapolation, but it's not feasible to calculate those errors, due to uncertainty about how occupants would respond in the extrapolated conditions.

Table 3
Applicable Ranges, Squad Models (mm, deg)

Variable	Lower Range, Extrapolated	Lower Range in Data	Upper Range in Data	Upper Range, Extrapolated
Seat Height (H30)	300	350	450	500
Seat Back Angle (A40)	0	0	10	20
Seat Cushion Angle (A27)	0	0	5	10

Data Analysis – Cutoff Contours

Figure 4 illustrates the three accommodation models presented in this report. Each contour is based on a "cutoff" principle, in that tangents to the contour are intended to divide the underlying population of Soldiers into quantiles. For example, a tangent to a 95% eyellipse divides the Soldier population such that 95% of Soldiers' eyes are predicted to lie on one side of the line and 5% on the other. Similarly, only 5% of Soldiers' helmets are expected to protrude beyond any tangent to the helmet contour, and similarly for knees. For additional utility, the knee contour includes tangent lines representing the shin and top of the thigh.

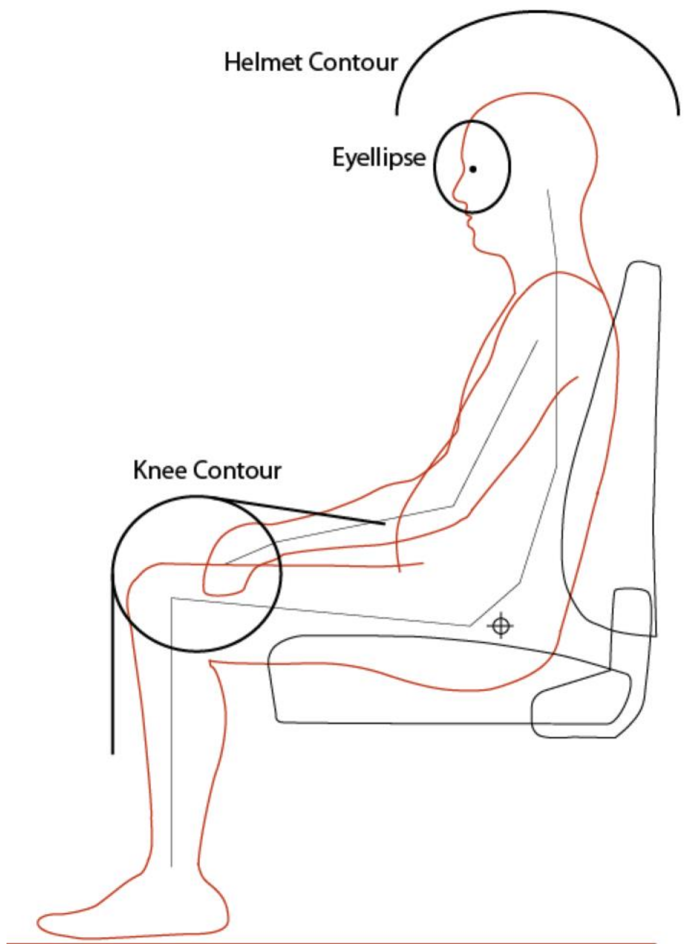

Figure 4. Illustration of side-view eyellipse, helmet contour, and knee contour.

Data Analysis – Eye Location

The *eyellipse* is a graphical construction based on the representation of the distribution of eye locations as a multivariate normal distribution. Under the reasonable assumption that the underlying eye location distribution is multinormal, all tangents to the eyellipse (either a line in 2D or a plane in 3D) divides the eye location distribution into constant fractions. For example, a tangent to the commonly used "95% eyellipse" divides the eye location distribution into 95%/5% fractions. This characteristic is exploited for vision analyses in which the goal is to ensure that a desired percentage of the occupant population can see a particular internal or external target without head movement.

The eyellipse models the distribution of eye locations as a three-dimensional normal distribution. The data analysis indicates that the distribution of right or left eye locations for a single gender population in a seat with minimal censoring due to headroom, knee room, and other clearance dimensions will be normal on each axis. Because the male and female eye location distributions overlap substantially, and because conducting analyses with separate male and female eyellipses would be cumbersome, a procedure has been developed to create a single eyellipse that approximates the cutoff behavior that would be obtained through weighted analyses using single-gender eyellipses. Second, the eyellipse is located in the vehicle with respect to the seat H-point. The eyellipse is configurable for the body dimension distributions of the squad population and gender mix.

Data Analysis – Helmet Contour

Helmet contours are constructed from the eyellipse based on a standard representation of side- and rear-view helmet profiles with respect to the eye. The profiles are given in Zerehsaz et al. (2014) and Appendix B. Because the squad eyellipse is square to grid (i.e., no side-view angle, unlike the driver eyellipse), constructing the helmet contour is straightforward. The front, top, and rear of the side-view contour are determined by constant offsets from the corresponding points on the eyellipse based on the helmet geometry. The lateral margin of the contour is based on inter-pupillary spacing (following J941, this is assumed to be 65 mm), plus an additional ±23 mm to account for head turn (following J1052, which prescribes 23 mm to account for outboard head turn).

Data Analysis – Knee Contour

The location of the suprapatella landmark was modeled to determine the distribution of knee locations. Regression equations give the distribution of this "top of knee" point, which is assumed to be normally distributed within gender. An ellipse is constructed for the top of knee, following the same methods used to determine the eyellipse. To account for the shin geometry, a top-of-shin point is calculated relative to the top-of-knee point, based on typical male geometry (see Reed 2006). The angle of the top-of-shin point relative to the top-of-knee (suprapatella) point is determined as a function of the leg (knee-to-ankle) angle. The top-of-knee ellipse is translated downward and forward, according to the calculated offset, and a new knee ellipse (contour) is constructed that spans the top of the top-of-knee ellipse and the front of the top-of-shin ellipse. A side-view shin (leg) contour line is constructed tangent to the knee contour at the angle of the leg, which is assumed to be vertical in the absence of other information. Similarly, a side-view thigh contour line is constructed tangent to the knee contour and parallel to the line from H-point to the suprapatella centroid.

RESULTS

Eyellipse

The squad seat is fixed, with no adjustments for the sitter. Seat height and seat back angle are potential inputs to the accommodation models, along with Soldier anthropometric variables. The statistical analysis demonstrated that the eyellipse could be effectively modeled square to grid, that is, without the downward angle in the driver eyellipse that is due to the covariance between torso height and fore-aft seat position. Both the X and Z coordinates of the eyellipse were influenced by body size, with the following regression equations:

EyeReHptX = 173 + 8.05 A40 - 0.117 Stature - 20.8 ln(BMI)
R^2_{adj} = 0.68, RMSE = 28.5 [8]

and

EyeReHptZ = -802 + 0.082 H30 - 0.675 A40 + 0.393 Stature + 1418 SH/S
R^2_{adj} = 0.79 RMSE = 18.1. [9]

Where A40 is the seat back angle (manikin torso angle) measured in degrees relative to vertical using the SAE J826 manikin, Stature is in mm, BMI is body mass index, defined by body weight in kg divided by stature in meters squared, and SH/S is erect sitting height divided by stature. The natural log of BMI is taken to obtain a distribution better approximated by the normal distribution.

Note that seat back angle (SAE A40) affects both the fore-aft and vertical location. The seat height effect (H30) indicates that higher seat heights are associated with less slouching, i.e., higher eye heights with respect to seat H-point. Eye locations are further forward with larger stature and larger BMI, and eye locations are higher with larger stature and a larger ratio of sitting height to stature.

Replacing the Soldier attributes by their weighted means, reference side-view eyellipse centroids are calculated. The male and female horizontal centroids with regard to H-point (which is also the Seating Reference Point, SgRP, since the seat is fixed) can be computed as

$$Xs_{centroid,male} = 173 + 8.05 A_{40} - 0.117\mu_{stature,male} - 20.8\mu_{\ln(BMI),male} \quad [10]$$

and

$$Xs_{centroid,female} = 173 + 8.05 A_{40} - 0.117\mu_{stature,female} - 20.8\mu_{\ln(BMI),female} \quad [11]$$

with $Xs_{centroid,male}$ and $Xs_{centroid,female}$ denoting male and female eyellipse centroids respectively. The associated standard deviations on the X axis are defined as

$$\sigma s_{x,male} = \sqrt{\left(-0.117\sigma_{stature,male}\right)^2 + \left(-20.8\sigma_{\ln(BMI),male}\right)^2 + \left(28.5\right)^2} \tag{12}$$

and

$$\sigma s_{x,female} = \sqrt{\left(-0.117\sigma_{stature,female}\right)^2 + \left(-20.8\sigma_{\ln(BMI),female}\right)^2 + \left(28.5\right)^2} \tag{13}$$

where $s s_{x,male}$ and $s s_{x,female}$ are male and female standard deviations of the eye locations on x axis.

The vertical eyellipse centroids are calculated as

$$Zs_{centroid,male} = -802 + 0.082H_{30} - 0.675A_{40} + 0.393\mu_{stature,male} + 1418\mu_{SH/S,male} \tag{14}$$

and

$$Zs_{centroid,female} = -802 + 0.082H_{30} - 0.675A_{40} + 0.393\mu_{stature,female} + 1418\mu_{SH/S,female} \tag{15}$$

with standard deviations calculated as

$$\sigma s_{z,male} = \sqrt{\left(0.393\sigma_{stature,male}\right)^2 + \left(1418\sigma_{SH/S,male}\right)^2 + \left(18.1\right)^2} \tag{16}$$

and

$$\sigma s_{z,female} = \sqrt{\left(0.393\sigma_{stature,female}\right)^2 + \left(1418\sigma_{SH/S,female}\right)^2 + \left(18.1\right)^2} \tag{17}$$

The back and front fore-aft eyellipse cutoffs (xs_1 and xs_2) are computed by iteratively solving

$$F_{11} = m\varphi\left(\frac{xs_1 - Xs_{centroid,male}}{\sigma s_{x,male}}\right) + (1-m)\varphi\left(\frac{xs_1 - Xs_{centroid,female}}{\sigma s_{x,female}}\right) \tag{18}$$

and

$$F_{12} = m\left(1-\varphi\left(\frac{xs_2 - Xs_{centroid,male}}{\sigma s_{x,male}}\right)\right) + (1-m)\left(1-\varphi\left(\frac{xs_2 - Xs_{centroid,female}}{\sigma s_{x,female}}\right)\right) \tag{19}$$

The top and bottom cutoffs of the vertical axis z, zs_1 and zs_2, are obtained similarly. The eyellipse is then constructed to lie within the side-view rectangle defined by these cutoffs.

Ensemble effects are applied to the reference centroid location. Relative to ACU, PPE and ENC shift the centroid forward 52 and 113 mm, respectively. The vertical location is unaffected by the ensemble level.

To construct the rear-view eyellipse, we use the vertical axis cutoffs obtained in the previous section. The lateral eye locations were not significantly affected by seat variables or body dimensions. As with the driver eyellipse, the lateral centroids of the left and right eyellipses for the squad position are ±32.5 mm from occupant centerline. The standard deviation of eye locations lateral eye location s_y is 15.35 mm. The lateral axis length can be calculated iteratively by solving for y in

$$1 - C = \phi\left(\frac{\frac{y}{2}}{s_y}\right) \qquad [20]$$

where C is the desired cutoff (e.g., 0.95), φ is the cumulative standard normal distribution, and the lateral axis length is y. Figure 5 shows side- and rear-view eyellipses.

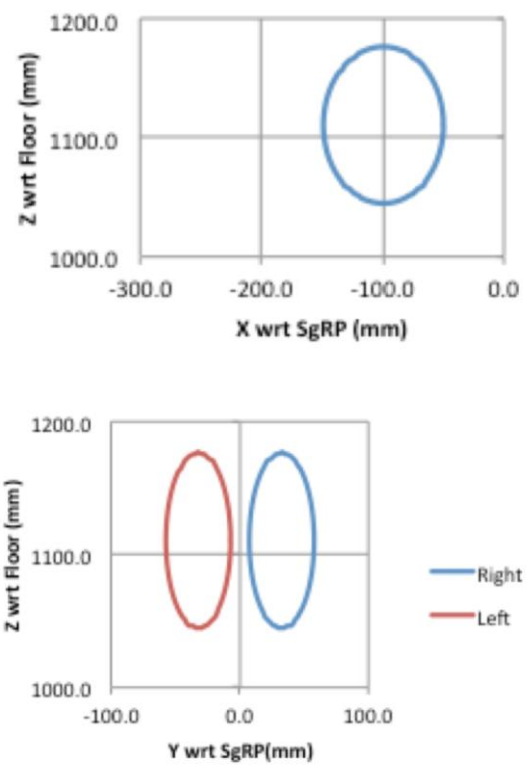

Figure 5. Side-view (top) and rear-view (bottom) eyellipses.

Helmet Contour

The construction of the squad helmet contour was constructed in the same manner as was described for the drivers (see UMTRI-2014-26, Zerehsaz et al. 2014). In side view, the helmet contour is represented by a second-order ellipse aligned with grid. The centroid is 75.8 mm above and 82.5 mm rearward of the eyellipse centroid. The front, top, and rear of the eyellipse are calculated as fixed offsets from the corresponding points on the eyellipse, to enable the helmet contour to automatically adjust for changes in the eyellipse geometry (for example, due to changes in gender mix or cutoff percentage).

The calculations for the squad are simpler than for the driver because the squad eyellipse is aligned to grid. Hence, the Z coordinate of the top of the eyellipse is the Z coordinate of the eyellipse centroid plus 0.5 times the Z axis length. The top of the helmet contour is 161.8 mm above the top of the eyellipse, due to the helmet dimensions. The front of the helmet contour is 52.2 mm forward of the front of the eyellipse. The rear of the helmet contour is 217.1 mm rearward of the rear of the eyellipse.

For the rear view, the head contour is constructed with two elliptical sections joined by a flat section at the top. Given that the height of the top of the contour is already specified by the side-view construction, we need only find the breadth relative to the side of eyellipse. Relative to the head centerline, the helmet extends 129.9 mm laterally. The additional clearance requirement due to variance in lateral head position is given by the eyellipse Y-axis length. Because the helmet has a nearly flat contour on the top, a better approximation of the clearance requirement is obtained by generating separate ellipsoid profiles for the left and right sides, using the eye centerlines (±32.5 mm from occupant centerline) as the contour ellipsoid lateral coordinate. The vertical helmet contour centroid coordinate has already been determined in side view. Hence, the (half) axis length for the rear-view helmet contour is 129.9 mm plus half the eyellipse lateral axis length. To account for head turn, both left and right contours are shifted outward by 23 mm, following SAE J1052. Figure 6 shows the rear-view helmet contour segments along with translated helmet profiles.

For three-dimensional applications, the helmet contour can be created by first generating an ellipsoid aligned to grid with the X and Z axis lengths given by the side-view calculations. The lateral axis length is 129.9 mm plus half the eyellipse lateral axis length. The bottom half of the ellipsoid is removed. The remainder is split along the centerline of the occupant in the squad seating position and the sides offset ±32.5 mm laterally to account for inter-eye spacing, then an additional ±23 mm to account for head turn. These sections can be extruded horizontally to the centerline to create a continuous contour.

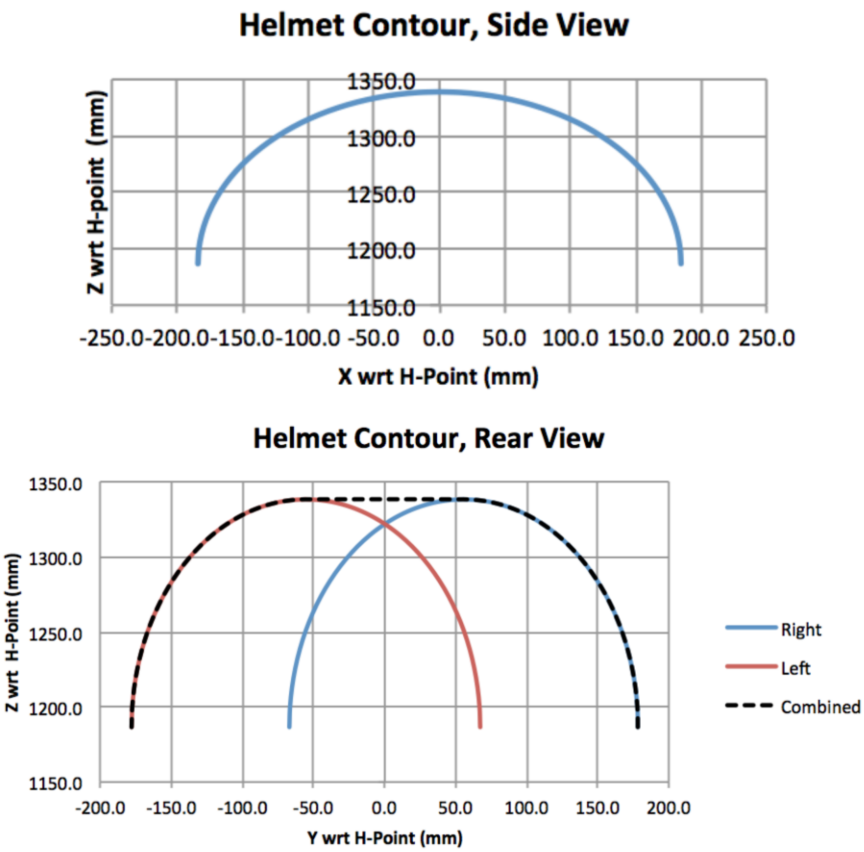

Figure 6. Side-view (top) and rear-view 95% cutoff helmet contours (rear-view includes both inboard and outboard shifts to account for head turn).

Knee Contour

A knee cutoff contour was modeled for the right knee using methods reported in Reed (2006). Note that the contours are reflected around the occupant centerline to model the left knee. The location of the suprapatella landmark at the upper, forward margin of the right patella was recorded for each Soldier and condition in the squad data set. Using regression analysis, we developed a statistical model predicting the suprapatella location based on anthropometric variables and some vehicle design variables. To account for knee width, we expanded the models laterally 110 mm, the average knee breadth in these data. The location of the top of the shin is estimated by translating the suprapatella ellipse down and forward. The magnitude of the translation is based on measurements of knee geometry reported in Reed (2006) and the direction is based on a predicted leg segment angle. Additional clearance lines are constructed representing the shin and the top of the thigh.

Suprapatella (Top-of-Knee) Landmark Locations – Three coordinate values were modeled:

PatellaX: Fore-aft location of the suprapatella landmark relative to seat H-point (negative values are further forward)

PatellaY: Lateral location of the suprapatella landmark relative to occupant centerline (positive values are further to the right, i.e., more outboard)

PatellaZ: Vertical location of the suprapatella landmark above the floor.

Table 9 shows the regression models for the ACU condition. The fore-aft knee locations with regard to H-point can be fairly well predicted ($R^2 = 0.62$) by stature (mm), ratio of sitting height to stature, seat height (mm) and the natural log of BMI ($\ln(kg/m^2)$). The lateral knee location is weakly related to the anthropometry variables but not the seat variables. The vertical knee location with respect to floor is a function of all potential predictors except for BMI. The R^2_{adj} for this regression is 0.91 indicating a strong relationship due to the association with body size (stature). The ensemble effect is reflected in the PatellaX variable. At the PPE level (IOTV), PatellaX is shifted forward 29 mm with respect to seat H-point. For ENC (SAW gunner with hydration pack), the PatellaX landmark is shifted forward 72 mm relative to the ACU condition. For a seat with hydration pack relief, the PPE value should be used.

Table 9
Knee Location Models for Squad Conditions

Variable	Constant	H30	A40	Stature	ln(BMI)	SH/S	R^2_{adj}	RMSE
PatellaX	-68.9	-0. 319		-0.202	-61.1	623	0.62	21.7
PatellaY	-484			0.204	48.8	306	0.27	31.1
PatellaZ	348	0.081	-1.97	0.313		-664	0.91	10.1

The calculation procedure is similar to the eyellipse. We first compute male and female means and standard deviations on X, Y, and Z axes, then iteratively obtain cutoff values that achieve the desired accommodation level.

The mean male and female knee locations are obtained using the models in Table 9 as:

$$Xk_{centroid} = -68.9 - 0.319H30 - 0.202m_{stature} - 61.1m_{\ln(BMI)} + 623m_{SH/S} \quad [21]$$

$$Yk_{centroid} = -484 + 0.204m_{stature} + 48.8m_{\ln(BMI)} + 306m_{SH/S} \quad [22]$$

$$Zk_{centroid} = 348 + 0.081H30 - 1.97A40 + 0.313m_{stature} - 664m_{SH/S} \quad [23]$$

where the μ values are set to the respective male and female population means.

The standard deviations of the knee locations for men and women are computed as

$$s_{PatellaX} = \sqrt{(0.211 s_{Stature})^2 + (-570 s_{SH/S})^2 + (21.7)^2} \quad [24]$$

$$s_{PatellaY} = \sqrt{(-0.227 s_{Stature})^2 + (-67.3 s_{\ln(BMI)})^2 + (31.1)^2} \quad [25]$$

$$s_{PatellaZ} = \sqrt{(0.291 s_{Stature})^2 + (-620 s_{SH/S})^2 + (10.1)^2} \quad [26]$$

X, Y, and Z cutoff values are obtained for the desired level of accommodation using the same procedures used for the eyellipse, taking into account the population gender mix (i.e., percent male).

The suprapatella landmark ellipsoid provides a guide for clearance at the top of the knee. To obtain the clearance at the top of the shin, the suprapatella ellipsoid is translated down and forward. The angle of the translation is dependent on the leg segment angle (angle of the vector from the right ankle joint to the right knee joint in side view with respect to vertical). For the conditions in the Seated Soldier Study, the leg posture was enforced to vertical. With the leg segment vertical, the translation from the suprapatella to shin point is 22.7 mm forward, 47.1 mm downward (Reed 2006). For applications with alternative leg postures (for example, due to the provision of foot support) the vector should be rotated by the magnitude of the leg segment angle to give the appropriate translation. For example, if the leg segment (knee to ankle vector in side view) is angled 45 degrees to vertical for a particular application, the vector (-22.7, 47.1) should be rotated by 45 degrees to obtain the appropriate translation from suprapatella point to shin point.

The knee contour ellipsoid spanning the suprapatella and top of shin ellipsoids is constructed such that the top of the knee contour has the same Z coordinate as the top of the suprapatella ellipsoid and the front of the knee contour has the same X coordinate as the front of the top-of-shin contour. The lateral clearance requirements are obtained by expanding the Y-axis dimension by 110 mm, the mean knee breadth. Figure 7 shows the overall knee contour ellipsoid along with the patella and shin ellipsoids.

Shin and thigh contours are depicted by constructing lines tangent to the knee contour at the orientation of the leg and thigh. The leg angle is defined as the vector from knee to ankle joint centers. The thigh angle is defined for these purposes as the sideview angle of the vector from the SgRP to the suprapatella centroid.

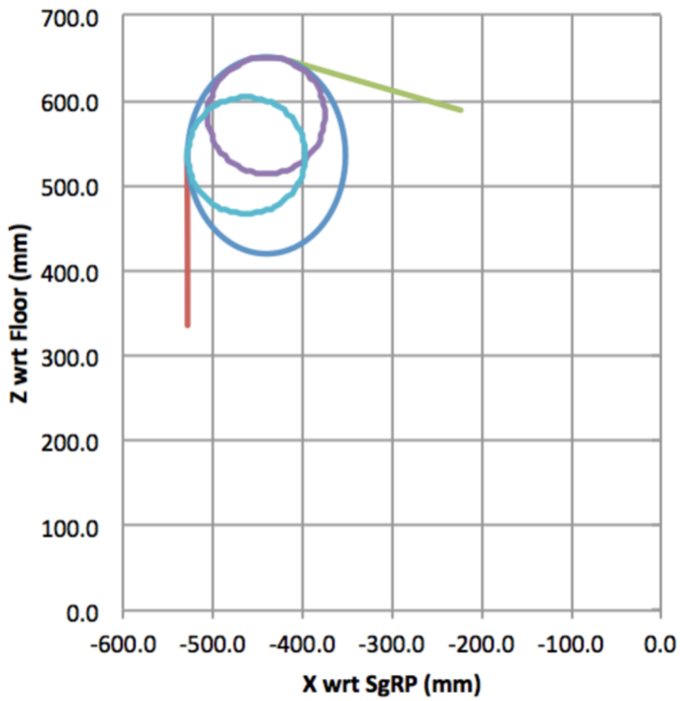

Figure 7. Example knee contour ellipsoid in side view, showing patella and tibia ellipses along with overall knee ellipsoid.

Use of Seat Index Point Tool

The models presented above are based on the seat H-point measured using the SAE J826 H-point manikin and procedures. Recent research has shown that the ISO 5353 Seat Index Point Tool (SIPT) can be used as an alternative measurement tool if the J826 manikin is not available (Reed and Ebert, 2014). Across a wide range of seating conditions, the seat index point (SIP) was on average 5 mm rearward of the J826 H-point. Consequently, an estimated H-point for use with these models can be generated by translating the SIP forward by 5 mm relative to the seat. This is equivalent to shifting the models themselves forward by 5 mm relative to a Seating Reference Point (SgRP) established using the SIPT rather than the J826 H-point manikin.

Example Calculations

The results of example calculations for each of the accommodation models are listed in Appendix A. The population input data are taken from the ANSUR II study (Gordon et al. 2015).

DISCUSSION

This report presents accommodation models for squad positions. The modeling methodology follows the methods developed for drivers and applied in the companion report (Zerehsaz et al. 2014). These are the first squad accommodation models based on Soldier data and the first to include the effects of PPE and body borne gear.

The primary limitation of these models is that only a small range of seat configurations was tested. The models are based on only two levels of seat height and seat back angle and may not extrapolate well to substantially different squad configurations. For example, the models may not be accurate for highly reclined back angles or seat heights lower than the recommended extrapolated value of 300 mm. Moreover, only a single seat was used. The seat was selected to have minimal bolstering and contour, to avoid effects unique to that seat. However, seats that have significant contour or other features, such as hydration pack relief or head support, might produce different postures. Additional data collection with Soldiers will be needed to address these issues.

The models are also limited by the particular uniform and gear conditions that were used in data collection. The ACU condition included standard-issue boots with an effective heel height of about 25 mm. Boots with thicker heels would be expected to have a small effect on posture, in particular raising the knees by the difference in heel thickness. More importantly, the PPE and ENC conditions were based on particular garb configurations. In the Seated Soldier Study, time restrictions precluded measurements with both the SAW and Rifleman kits. Consequently, the SAW gunner kit was chosen for squad data collection because it was the larger of the two kits considered. (Driver testing in the Seated Soldier Study was conducted with a Rifleman kit.) A different ensemble may have produced different postures and space claim requirements. However, for the current work, the most critical effect of the gear was to shift the Soldiers forward on the seat. Consequently, the results are applicable to any ensemble that includes an IOTV with or without a hydration pack.

The IOTV and ACH geometry had a significant effect on Soldier posture and contour definitions. The effects of a different helmet (or the additional of helmet-mounted equipment) could be accounted for by amending the helmet contour model. Any additional gear or equipment that interacts with the seat could cause the Soldier to sit differently. One important limitation of the ENC conditions is that a single hydration pack was used. Soldiers not wearing a hydration pack or sitting on a seat with an opening designed to accommodate the hydration pack would be expected to sit somewhat differently. Although new data would be the best way to account for different seats, using the PPE models for ENC situations with hydration pack relief is a reasonable approach.

The data on which these models are based were gathered from a convenience sample of Soldiers at three Army posts in 2012. However, the modeling methodology is not strongly dependent on the representativeness of the sample. Even relatively large changes in the anthropometric distributions of Soldiers would not have important effects on the validity of these models.

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APPENDIX A

EXAMPLE CALCULATIONS

All dimensions in mm unless otherwise noted.

Population (ANSUR II, Gordon et al. 2015)

ANSUR II (2012 Army Data)

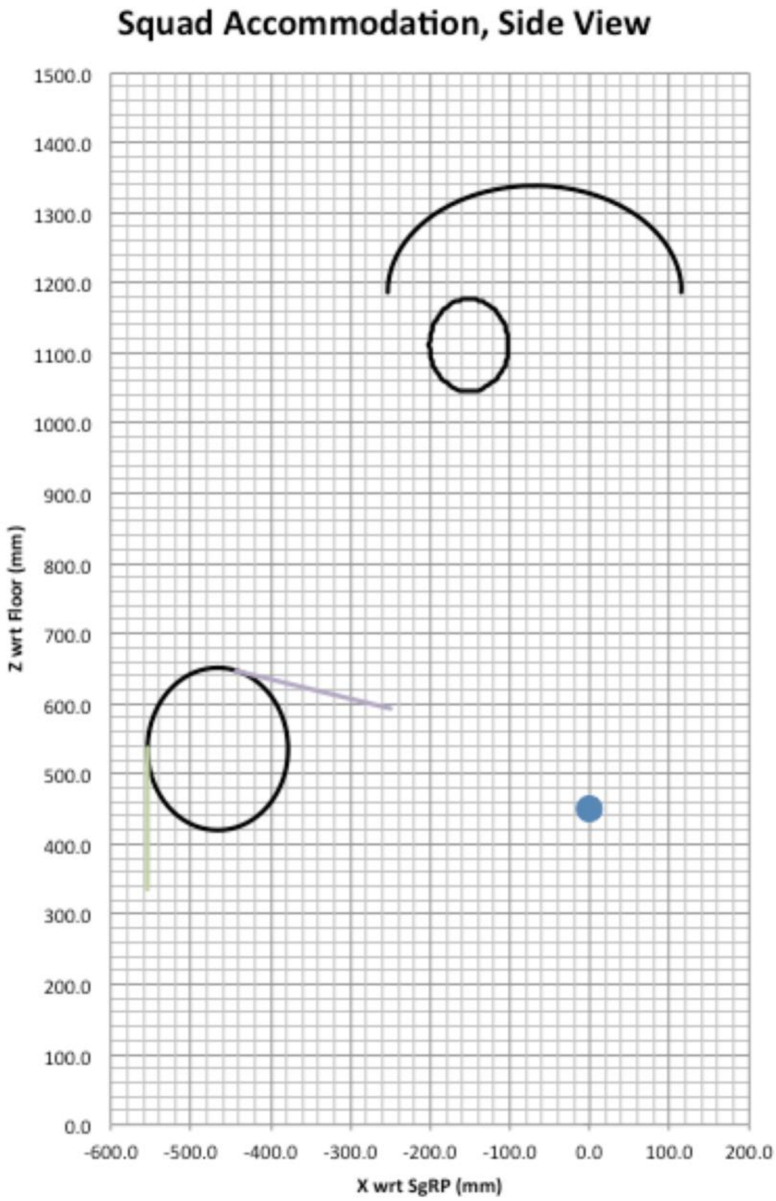
Dimension	**Men**		**Women**	
	Mean	SD	Mean	SD
Stature (S), mm	1756	68.6	1628	64.2
Erect Sitting Height (SH), mm	918	35.7	857	33.1
Stature minus Sitting Height (SSH), mm	837	46.5	772	44.4
SH/S, --	0.523	0.0135	0.526	0.0141
Log(BMI)*, log(kg/m^2)	3.31	0.146	3.23	0.135

*Note -- this is natural log of BMI. In Excel, use = LN(BMI)

Fraction Male	0.9

Vehicle Geometry

A40	0	mm
H30	450	mm
Garb Level	PPE	ACU, PPE, ENC
Seat Has Hydration Pack Relief	No	
Calibration Tool	J826	
Reference Point Offset	**0**	


Squad Accommodation, Side View
Z wrt Floor (mm)
1500.0
1400.0
1300.0
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-600.0
-500.0
-400.0
-300.0
-200.0
-100.0
0.0
100.0
200.0
X wrt SgRP (mm)

EYELLIPSE

Eyellipse Centroids	X (mm)	Y (mm)	Z re Floor (mm)	
Right	-151.5	32.5	1110.8	<- subtract H30 to get value wrt SgRP (H-point)
Left	-151.5	-32.5	1110.8	<- subtract H30 to get value wrt SgRP (H-point)

Side View of Eyellipses (X, Z)		
Eyellipse Angle (X' Axis wrt Horizontal)	0.0	deg
Axis Length (X)	99.2	mm
Axis Length (Z)	131.9	mm
Rear View of Eyellipses (Y, Z)		
Axis Length (Y)	50.5	mm
Axis Length (Z)	131.9	mm

HELMET CONTOUR

Construction Centroids	X (mm)	Y (mm)	Z (mm)	
Right	-69.0	32.5	1186.6	<- subtract H30 to get value wrt SgRP (H-point)
Left	-69.0	-32.5	1186.6	

Side View of Helmet Contour (X, Z)		
Axis Length (X)	368.5	mm
Axis Length (Z)	303.9	mm
Rear View of Helmet Contour (Y, Z)		
Axis Length (Y)	245.3	mm
Axis Length (Z)	303.9	mm

KNEE CONTOUR

Knee Centroids	X (mm)	Y (mm)	Z re Floor (mm)
Right	-466.4	192.9	535.5
Left	-466.4	-192.9	535.5

Side View of Knee Contours (X, Z)		
Axis Length (X)	176.3	mm
Axis Length (Z)	231.6	mm

Rear View of Knee Contours (Y, Z)		
Axis Length (Y)	291.3	mm
Axis Length (Z)	231.6	mm

APPENDIX B

HELMET CONTOURS

Sagittal		Coronal	
X	Z	Y	Z
-52.2	53.4	-129.9	-11.0
-51.8	56.7	-129.0	-5.3
-51.2	60.0	-128.1	0.2
-50.6	63.3	-127.2	5.7
-50.0	66.4	-126.3	10.9
-49.3	69.5	-125.4	16.1
-48.6	72.5	-124.5	21.1
-47.8	75.5	-123.5	25.9
-47.0	78.4	-122.6	30.6
-46.1	81.2	-121.7	35.2
-45.2	83.9	-120.7	39.7
-44.3	86.6	-119.8	44.0
-43.3	89.2	-118.8	48.2
-42.3	91.8	-117.9	52.3
-41.3	94.3	-116.9	56.3
-40.2	96.7	-115.9	60.1
-39.0	99.1	-114.9	63.8
-37.9	101.4	-113.9	67.5
-36.7	103.7	-112.9	71.0
-35.4	105.9	-111.9	74.4
-34.2	108.1	-110.9	77.7
-32.9	110.2	-109.9	80.9
-31.5	112.2	-108.9	84.0
-30.2	114.2	-107.8	87.0
-28.8	116.2	-106.8	89.9
-27.3	118.0	-105.8	92.8
-25.9	119.9	-104.7	95.5
-24.4	121.7	-103.6	98.1
-22.9	123.4	-102.6	100.7
-21.3	125.1	-101.5	103.2
-19.8	126.7	-100.4	105.6
-18.2	128.3	-99.3	107.9
-16.6	129.9	-98.2	110.1
-14.9	131.4	-97.1	112.3
-13.3	132.8	-96.0	114.4
-11.6	134.2	-94.8	116.4
-9.9	135.6	-93.7	118.3
-8.2	136.9	-92.6	120.2
-6.4	138.2	-91.4	122.0
-4.6	139.5	-90.3	123.7

-2.9	140.7	-89.1	125.4
-1.0	141.8	-87.9	127.1
0.8	143.0	-86.8	128.6
2.6	144.0	-85.6	130.1
4.5	145.1	-84.4	131.6
6.4	146.1	-83.2	133.0
8.2	147.1	-82.0	134.3
10.2	148.0	-80.7	135.6
12.1	148.9	-79.5	136.9
14.0	149.8	-78.3	138.0
16.0	150.6	-77.0	139.2
17.9	151.4	-75.8	140.3
19.9	152.2	-74.5	141.4
21.9	152.9	-73.3	142.4
23.9	153.6	-72.0	143.4
25.9	154.3	-70.7	144.3
27.9	154.9	-69.4	145.2
29.9	155.5	-68.1	146.1
31.9	156.1	-66.8	146.9
34.0	156.6	-65.5	147.7
36.0	157.1	-64.2	148.5
38.1	157.6	-62.9	149.2
40.1	158.1	-61.5	149.9
42.2	158.5	-60.2	150.6
44.2	158.9	-58.9	151.2
46.3	159.3	-57.5	151.8
48.4	159.6	-56.2	152.4
50.5	159.9	-54.8	152.9
52.5	160.2	-53.4	153.5
54.6	160.5	-52.0	154.0
56.7	160.7	-50.6	154.5
58.8	160.9	-49.3	155.0
60.9	161.1	-47.9	155.4
63.0	161.3	-46.4	155.8
65.1	161.4	-45.0	156.2
67.1	161.6	-43.6	156.6
69.2	161.6	-42.2	157.0
71.3	161.7	-40.8	157.3
73.4	161.8	-39.3	157.7
75.5	161.8	-37.9	158.0
77.6	161.8	-36.4	158.3
79.6	161.8	-35.0	158.6
81.7	161.7	-33.5	158.8
83.8	161.7	-32.0	159.1
85.8	161.6	-30.6	159.3
87.9	161.5	-29.1	159.6

89.9	161.4	-27.6	159.8
92.0	161.2	-26.1	160.0
94.0	161.1	-24.6	160.2
96.0	160.9	-23.1	160.4
98.1	160.7	-21.6	160.5
100.1	160.4	-20.1	160.7
102.1	160.2	-18.6	160.8
104.1	159.9	-17.1	161.0
106.1	159.6	-15.6	161.1
108.0	159.3	-14.1	161.2
110.0	159.0	-12.5	161.3
112.0	158.7	-11.0	161.4
113.9	158.3	-9.5	161.5
115.9	157.9	-7.9	161.6
117.8	157.5	-6.4	161.7
119.7	157.1	-4.8	161.7
121.6	156.6	-3.3	161.8
123.5	156.2	-1.7	161.8
125.4	155.7	-0.2	161.8
127.3	155.2	1.4	161.8
129.1	154.7	3.0	161.8
131.0	154.2	4.5	161.8
132.8	153.6	6.1	161.8
134.6	153.0	7.6	161.8
136.4	152.4	9.2	161.7
138.2	151.8	10.8	161.7
139.9	151.2	12.4	161.6
141.7	150.5	13.9	161.5
143.4	149.9	15.5	161.4
145.2	149.2	17.1	161.3
146.9	148.5	18.7	161.2
148.6	147.7	20.2	161.0
150.2	147.0	21.8	160.9
151.9	146.2	23.4	160.7
153.5	145.4	25.0	160.5
155.2	144.6	26.6	160.3
156.8	143.8	28.1	160.1
158.4	143.0	29.7	159.8
159.9	142.1	31.3	159.6
161.5	141.2	32.9	159.3
163.0	140.3	34.4	159.0
164.5	139.3	36.0	158.7
166.0	138.4	37.6	158.3
167.5	137.4	39.2	157.9
169.0	136.4	40.7	157.5
170.4	135.4	42.3	157.1

171.8	134.4	43.9	156.7
173.2	133.3	45.4	156.2
174.6	132.2	47.0	155.7
175.9	131.1	48.5	155.2
177.3	130.0	50.1	154.6
178.6	128.8	51.6	154.0
179.9	127.6	53.2	153.4
181.2	126.4	54.7	152.7
182.4	125.2	56.2	152.0
183.7	123.9	57.8	151.3
184.9	122.6	59.3	150.5
186.1	121.3	60.8	149.7
187.2	120.0	62.3	148.8
188.4	118.6	63.8	147.9
189.5	117.3	65.4	147.0
190.6	115.8	66.9	146.0
191.7	114.4	68.3	145.0
192.8	112.9	69.8	143.9
193.8	111.4	71.3	142.8
194.8	109.9	72.8	141.6
195.8	108.3	74.2	140.4
196.8	106.7	75.7	139.1
197.7	105.1	77.1	137.8
198.6	103.5	78.6	136.4
199.5	101.8	80.0	134.9
200.4	100.1	81.4	133.4
201.3	98.3	82.9	131.8
202.1	96.6	84.3	130.2
202.9	94.7	85.7	128.5
203.7	92.9	87.0	126.7
204.5	91.0	88.4	124.9
205.2	89.1	89.8	123.0
206.0	87.1	91.1	121.0
206.7	85.2	92.5	118.9
207.3	83.1	93.8	116.8
208.0	81.1	95.1	114.6
208.6	79.0	96.4	112.3
209.2	76.8	97.7	109.9
209.8	74.6	99.0	107.5
210.4	72.4	100.3	104.9
210.9	70.2	101.5	102.3
211.4	67.9	102.8	99.5
211.9	65.5	104.0	96.7
212.4	63.1	105.2	93.8
212.8	60.7	106.4	90.7
213.2	58.2	107.6	87.6

213.6	55.7	108.8	84.4
214.0	53.1	109.9	81.1
214.4	50.5	111.0	77.6
214.7	47.9	112.2	74.1
215.0	45.2	113.3	70.4
215.3	42.4	114.3	66.6
215.6	39.6	115.4	62.7
215.8	36.8	116.5	58.7
216.0	33.8	117.5	54.6
216.2	30.9	118.5	50.3
216.4	27.9	119.5	45.9
216.6	24.8	120.5	41.4
216.7	21.7	121.4	36.7
216.8	18.5	122.4	31.9
216.9	15.3	123.3	27.0
217.0	12.0	124.2	21.9
217.0	8.7	125.1	16.7
217.0	5.3	125.9	11.3
217.1	1.8	126.7	5.8
217.0	-1.7	127.6	0.1
217.0	-5.3	128.3	-5.7
216.9	-8.9	129.1	-11.7